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(54) Invention Name: Graphite containing high molybdenum wear resistant cast iron

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1. Name of the invention:

Graphite containing high molybdenum wear resistant cast iron

2. Patent claimed ranges

(1) Chemical composition by weight percent

C: 2.0-3.5%, Ni: 2.0-12.0%, Si: 1.6-3.5%, Cr: 1.0-5.0%, Mn: less than 1.5%,  
Mo: 2.0-16.0%. The rest is primarily iron. The above chemical composition  
characterizes a graphite-containing high molybdenum wear resistant cast iron.

3. The detailed description of the invention

(Related industrial application) The present invention is related to heat and wear resistant  
cast iron, which is primarily used to make hot rolling mill rolls.

(Current technology)

From metallurgical point of view, the high chromium cast iron has excellent wear resistance  
because of high hardness carbides. High chromium cast iron has been used to make external layer  
of composite roll in hot rolling section, especially for hot plate rolling mill roll. However, high  
chromium cast iron roll has a poor thermal conductivity and low in heat resistance. Therefore, the  
current inventor proposed to use graphite containing high chromium cast iron as roll material in  
Japan Patent 61-16415. This type of roll material can increase both wear and heat resistance and  
also improve rolling performance.

(Problems to be solved)

The above high chromium cast with precipitated graphite only has adequate wear and heat  
resistance. Hopefully wear resistance can be further improved.

The key point in the present invention is to provide a wear resistant cast iron containing  
precipitated graphite without losing its heat resistance.

(Methods used to solve the problems)

To achieve the above objective the present invention with precipitated graphite contains the  
following chemical composition (by weight percent):

C: 2.0-3.0%, Ni: 2.0-12.0%, Si: 1.6-3.5%, Cr: 0.1-5.0%, Mn: 1.5%, Mo:  
2.0-16.0%, the rest is primarily iron.

C: 2.0-3.5%,

Carbon combines molybdenum to form molybdenum carbide, and precipitates fine graphite with

the promoted effects from silicon and nickel. Molybdenum carbide will not be enough and it is also difficult for graphite to precipitate when carbon is less than 2.0%. On the other hand, excessive graphite formation will deteriorate wear resistance when carbon is higher than 3.5%.

Si: 1.6-3.5%

Because of high content in carbide forming elements like molybdenum and chromium, it is necessary to have silicon to precipitate graphite from the alloy. Such effect can not be obtained if silicon content is less than 1.6% while excessive precipitation of graphite will worsen wear resistance when silicon is beyond 3.5%. Silicon content should be lower during melting and add a portion of silicon as inoculation to be within the specification, which is helpful to the graphite precipitation.

Mn: less than 1.5%

It is necessary to have manganese to remove the harmful effect of sulfur. However, manganese will worsen mechanical properties, especially toughness, when the amount is higher than 1.5%.

Ni: 2.0-12.0%,

Nickel can improve matrix microstructure and also promote graphite precipitation. It is difficult for graphite to precipitate when nickel is less than 2.0%. On the other hand, similar to the silicon effect to graphite precipitation, excessive precipitation of graphite will worsen wear resistance when nickel is higher than 12.0%. Higher nickel will also increase residual austenite, which expands to cause surface defects when decomposed under rolling compression.

Cr: 0.1-5.0%

Chromium combines carbon to form complex molybdenum carbides and also enter matrix as solid solute atoms. There is no obvious strengthening effect if Ni is less than 0.1% and chromium will retard graphite precipitation if the amount exceeds 5.0%.

Mo: 2.0-16.0%

Molybdenum enters into matrix in the form of solid solute atoms to increase heat resistance and also improve high temperature wear resistance. Molybdenum forms alloy carbide to improve wear resistance. There is no obvious effect if the amount is less than 2.0% and will retard graphite precipitation if the amount is higher than 16.0%.

The rest is iron and impurities in the present invention besides the above alloy elements.

Sulfur can increase brittleness of the alloy therefore sulfur should be limited to 0.12%. On the other hand, phosphor also increases brittleness of materials and phosphor should be controlled to minimum level. Phosphor eutectic can improve wear and heat resistance, therefore phosphor is allowed to be less than 0.8%. To improve microstructure and refine carbides, B (<1.0%), V (<1.0%), and Nb (<1.0%) can be used to replace iron. For the above alloy nickel content is between 2.0-12.0% , which can be replaced by less than 10% nickel and 0.5-5.0% copper. Less than 10% nickel is benefit to reduce residual austenite. Moreover, addition of copper can promote graphite precipitation and strengthen Pearlite microstructure. There is no obvious effect when

copper is less than 0.5%, precipitation of copper from matrix will worsen mechanical properties when copper content exceeds 5.0%. Furthermore, it is difficult to precipitate graphite when nickel and copper is less than 2.0%. However, excessive graphite precipitation will worsen wear resistance when the total of nickel and copper is higher than 12.0%.

In the present invention of the high molybdenum cast iron material, molybdenum is used to form carbide to improve heat resistance; chromium is used to strengthen molybdenum carbide; nickel, chromium, and molybdenum are used to strengthen the matrix. These factors contribute to the excellent wear resistance of the alloy. On the other hand, silicon and nickel are used to promote graphite precipitation to ensure good heat resistance. Hence the present invention is suitable for external layer material of composite roll. Because of the strengthened matrix, the invention also has excellent impact resistance and therefore this material can also be used to make bulk rolls. Moreover, the present invention can be used to make wear and heat resistant mechanical components such as metal permanent molds.

#### (Examples)

High molybdenum cast iron containing graphite has been described in the above sections, advanced cast iron and ductile iron as well as graphite steel or other cast irons with good toughness can be used to make the inner portion of the composite roll. The chemical composition of ductile iron is given below (by weight percent):

C: 3.0-3.8%, Ni: less than 2.0%, Si: 1.8-3.0%, Cr: less than 1.0%, Mn: 0.3-1.0%, Mo: less than 1.0%, P: less than 0.1%, Mg: 0.02-0.1%, S: less than 0.02%, the balance being Fe.

Centrifugal casting method is used to make the external layer of composite roll and the static pouring method is used to make the inner portion. Because of its simplicity centrifugal casting is widely used to make composite rolls.

It is a good way to make an intermediate layer to improve interlayer bonding strength in making composite rolls. The intermediate layer is poured after external layer was formed by centrifugal casting method. Adamite alloy is suitable for making the intermediate layer and its chemical composition is listed below (by weight percent);

C: 1.0-2.5%, Ni: less than 1.5%, Si: 0.5-1.5%, Cr: less than 3.0%, Mn: 0.5-1.5%, Mo: 2.0-5.0%, P: less than 0.1%, S: less than 0.1%, the rest is Fe.

The inner portion of the composite roll can also be made as a shell, which is produced by centrifugal casting process when the external layer is centrifugally cast. Heat treat the above composite rolls at 450-600 C to stabilize the microstructure, especially to remove any residual austenite. Another heat treatment method is to heat up the rolls to austenizing temperature, forced air cool with water spray and then temper these rolls again.

Besides making external layer of composite rolls, the high molybdenum graphite containing cast iron can also be used to make other mechanical components, such as various permanent molds. The followings are several examples.

#### Example A

(1) Melt alloys according to chemical compositions given in table 1(wt%, the balance is iron), heat treat these casting samples. Sample No. 1-4 are inventive alloys and No.5 is prior art alloy (high chromium iron with precipitated graphite).

##### \* Heat treatment

Quenching	1000 °C for 5 hours
Tempering	540 °C for 15 hours

Use materials from table 1 to do hardness, oxidation, and wear tests.

Wear test set-up is shown in Figure 1, sample 1 is fastened on the spindle by a set screw 3. The other side is a dead weight as applied load. Check if oxidation occurs by measuring the torque. The test conditions are as follows;

Sample dimensions	10x351
Stainless steel plate 15(SUS 430)	
Speed	300 rpm
Applied load	30 kgf
Environment	Atmosphere (no lubrication)

Rolling wear test set up is shown in Figure 2. Sample 11 was rolled by a stainless steel roll of 100 mm in diameter and 5 mm in width, measure sample 11 surface depth.

Applied load	6 kgf
Testing time	30 minutes
Testing temperature	25 °C

The test results are given in table 2, O in the table shows no oxidation occurred. Use prior art alloy as 1 for the amount of wear. According to results in table 2, inventive samples No. 1-4 and prior art sample No. 5 have no oxidation. However, the wear ratio of inventive sample and prior art sample is 9/10, indicating wear resistance has been improved in the inventive sample.

An actual example of making a composite roll with 700 mm in diameter and 1450 mm in length.

(1) The external layer alloy composition is in table 3, the high molybdenum graphite precipitated cast iron is poured into centrifugal casting mold and the thickness of the shell is 80 mm.

(2) Stop permanent mold rotation after 20 minutes the external was poured, then pour ductile iron into the external shell to form the inner portion of the roll. Use a cover on top of the roll.

(1) After solidification totally completes, heat treat and machine the casting.

For inventive samples No. 1 and 3

Quenching	1000 C for 5 hours
Tempering	540 C for 15 hours

For inventive samples No. 2 and 4

Stabilizing treatment 500 C for 15 hours

- (2) Ultrasound test result shows there is an excellent bonding between the external and inner layer. The thickness of the external layer is given in table 4. Hardness and graphite area are also listed in the table. The microstructure of the external layer is composed of graphite and molybdenum carbide.

(Advantages of the invention)

The above tests confirm that the high molybdenum (Mo: 2.0-16.0%) cast iron with precipitated graphite has excellent wear and heat resistance as well as good toughness because of large amount of molybdenum carbide and the strengthening of the matrix plus the precipitation of graphite. The alloy is suitable for making rolls and other mechanical components that require many good material properties.

4. Brief description of drawings; Figure 1 is a schematic drawing of oxidation experimental set-up, figure 2 is a schematic drawing of wear test experimental set-up.